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The effect of orthographic regularity on children's handwriting production

Sonia Kandel and Sylviane Valdois

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Introduction

Handwriting is a linguistic motor task involving different processing stages. From the intention of writing to the actual movement execution, there are different processing levels such as semantic activation, syntax construction, spelling recovery, allograph selection, size control and muscular adjustment (Van Galen, 1991). This study focuses on the spelling level. It examines how specific linguistic characteristics of orthographic representations –such as orthographic irregularity- affect the organisation of handwriting movements during spelling acquisition.

Motor programming in handwriting does not merely require the activation of letter strings at the spelling module (Teulings, Thomassen, & Van Galen, 1983; Van Galen, Smyth, Meulenbroek, & Hylkema, 1989). It is mediated by multi-dimensional orthographic representations that store information such as the consonant and vowel status of letters and the syllabic structure of the word (Caramazza & Miceli, 1990; Caramazza, Miceli, Villa, & Romani, 1987; McCloskey, Badecker, Goodman-Schulman, & Aliminosa, 1994; Wing & Baddeley, 1980). Experimental studies also revealed that specific linguistic characteristics of orthographic representations require additional processing – a supplementary cognitive load- that affect the temporal and spatial features of handwriting production (Kandel, Alvarez, & Vallée, submitted; Orliaguet & Boë, 1993; Orliaguet, Zesiger, Boë, & Mounoud, 1993; Wing, 1980). Zesiger, Mounoud, and Hauert (1993), for example, showed that adults' movement time and trajectory length when writing pseudo-words was systematically higher than when writing words. These values

increased even more when the pseudo-words had embedded infrequent trigrams. The authors suggested that these increases translate a cognitive load arising from the presence/absence of an orthographic representation in the lexicon and/or a more complicated search process in the case of non frequent trigrams. The present experiment attempts to shed some light on whether specific orthographic irregularities in words affect handwriting production during spelling acquisition.

Studies on children handwriting production support the idea that the linguistic characteristics of orthographic representations at the spelling level modulate movement execution. Søvik, Arntzen, Samuelstuen, & Heggberget (1994) showed that 9 year old children produce lower movement durations when writing frequent words than less frequent words. In another research, Kandel and Valdois (in press), showed that French first to fifth graders programmed handwriting movements according to their syllable structure. The children wrote very familiar words and pseudo-words on a digitiser. Movement time analysis revealed that the children programmed the gesture to produce the first syllable before starting to write. There was a systematic duration increase at the first letter of the second syllable irrespective of lexical status, item length and school level. These duration increases were higher for pseudo-words than for words. This pattern of results indicates that the children programmed the movement to write the second syllable during the production of its first letter. During movement production, there were concurrent processes -information of different representational levels- that were active simultaneously (Van Galen, 1991; Van Galen, Meulenbroek, & Hylkema, 1986), resulting in duration increases. It should be noted however, that the younger children, mostly first graders, wrote some items (in general pseudo-words) letter by letter.

The present study examined how another linguistic characteristic -orthographic regularity- affects handwriting production during the acquisition of writing skills. The effect of orthographic regularity has been widely studied (Sprenger-Charolles, Siegel, Béchennec, & Serniclaes, 2003; Waters, Bruck, & Seidenberg, 1985). Orthographic regularity refers to the way in which a language associates letters to sounds. To learn how to read and write, the child must acquire detailed orthographic representations of regular and irregular words and access them globally (Frith, 1985, 1986). Regular words have straightforward relationships between graphemes and phonemes, like *camera* = / kameRa/. They can be read and/or written correctly by applying analytic grapho-phonological conversion mechanisms. Irregular words require global processing and can only be read/written by accessing orthographic representations. To acquire irregular words, the child has to be aware of certain spelling peculiarities, e.g. the *e* in *femme* is pronounced /a/ (/fam/) instead of /e/. In the present study, we investigated whether the processing of these orthographic peculiarities constitutes a cognitive load in handwriting production during written language acquisition. Bloemsaat, Van Galen and Meulenbroek (2003) have shown that orthographic irregularity slows down performance when typewriting Dutch words. There was an increase in preparation time and typing time. In line with this study, we hypothesized that when acquiring irregular words, orthographic irregularities constitute a supplementary processing load that results in an increase in movement time at the location of the irregularity. In our study, the orthographic irregularity was located at the beginning, middle or end of words acquired early or late. If the child is familiar with the word, he/she can write it down by recovering information from the corresponding orthographic representations. In this case, the processing of irregular and regular words should be the same and yield no duration differences for

words acquired early. A different mechanism operates when writing unfamiliar. The child applies a phonological recoding mechanism that works successfully when writing regular words. But, when the child has to write an unfamiliar irregular word, he/she has to memorize the spelling of the whole word and remember the identity and location of the orthographic irregularity. This operation constitutes a supplementary cognitive load that results in an increase in production time. We expected orthographic irregularity to affect first graders more than second graders. Second graders have been more exposed to written language than first graders, so they should have more spelling information stored in memory and therefore recover the spelling of regular and irregular words globally rather than analytically (Share, 1995, 1999).

Method Participants

Fourty-four right-handed children participated in the experiment. There were 22 first graders (mean age 6;8 ranging from 6;1 to 7;3, standard deviation 4 months) and 22 second graders (mean age 7;7 ranging from 7;0 to 8;2, standard deviation 3 months). They were all pupils of two schools of the Grenoble urban area and were tested throughout the month of March 2002. We made sure that their mother tongue was French. The teachers reported the reading method was global and phonological, since it also focused on grapheme-phoneme correspondences. None of the subjects were repeating nor skipping a grade. They were attending their grade at the regular age. They all had normal or corrected-to-normal vision and reported no hearing impairments. No learning disability, brain or behavioural problems were reported. School attendance was regular.

Material and procedure

The stimuli consisted of 24 six and seven letter French words (see Appendix). 12 words were orthographically regular and the other 12 words were orthographically irregular. The irregularity of the words was situated at the beginning of the word (e.g. ***qu****atre*), in the middle (e.g. *ca****h****ier*), and at the end (e.g. *solda****t***). We used the Dubois-Buyse scale as a reference for age of acquisition (Ters, Mayer, & Reichenbach, 1988). This scale distributes the most familiar French words for children in 43 sets of increasing familiarity. The words in the first sets are learnt before the words in the last sets. In this experiment, the selected words could either be acquired early (sets 11 to 17) or acquired late (sets 22 to 28). The orthographically regular words were matched to the irregular words in age of acquisition and number of letters.

The children saw each word on the centre of the screen of a laptop (Sony Vaio PCG-FX203K) written in lowercase Times New Roman size 18. Word presentation was preceded by an auditory signal and a fixation point (200 ms duration). The participants' task was to copy the item on the digitiser (Wacom Intuos 1218, sampling frequency 200 Hz, accuracy 0.02 mm). The children had to write the word that was presented on the screen so that the correct spelling of the word was available since the beginning until the end of the writing process. The digitiser was connected to a computer that monitored the movement the child produced to write the word. The children copied the words as they did "when writing at school" (i.e. in cursive handwriting). There were no time limits or speed constraints. They had to write (with an Intuos Inking Pen) on a lined paper that was stuck to the digitiser (the vertical limit was 0.8 cm and the horizontal limit was 17 cm). Once the child finished writing the word, the experimenter presented the following one. Two practice items preceded the experiment.

Data processing and analysis

As many studies on handwriting production, we used movement duration as an indicator of a supplementary processing load during motor programming. We followed the standard procedure of movement analysis. First, the data were smoothed with a Finite Impulse Response filter (Rabiner & Gold, 1975) with a 12 Hz cut-off frequency. To segment each word into its letter constituents, we used geometric (cuspids and curvature maxima) and kinematic (velocity minima) criteria. With this segmentation procedure we obtained the duration of each letter in the word. The duration measure concerned actual movement execution (the time the child took to look at the word, or any other kind of pause, were excluded). In order to compare the duration of letters that have different spatial configurations, the duration of each letter was divided by the number of strokes it contained. To define the number of strokes, we followed the segmentation procedure presented by Meulenbroek and Van Galen (1990). An *l*, for instance, has two strokes: an up-stroke and a down-stroke. If the duration of the *l* was 180 ms, then the mean stroke duration was 180/2 = 90 ms. The mean stroke duration was divided by the sum of all the mean stroke durations of the word, and then, converted to percentages. This normalization procedure provides information on the global organization of the handwriting movement. It reveals the distribution of the duration throughout the word. Mean stroke duration increases at specific locations result from parallel processing of orthographic and motor information. When one of these variables, like orthographic irregularity, requires additional processing, then duration percentages increase (Van Galen, 1991; Van Galen et al., 1986). In addition, mean stroke duration percentages allow comparisons among all participants, from very slow to very fast ones. For instance, the mean stroke duration of a given letter can be 100 ms for one child and 200 ms for another, but if the duration percentages for this letter for both children are around 17%, then both children program their movement in the same manner. This is very important in this study because the children's age varied from six to eight, which is a critical period of motor development. Indeed, many authors have shown that absolute movement duration decreases as the child grows up (Meulenbroek & Van Galen, 1986, 1988, 1989; Mojet, 1991; Zesiger et al., 1993). For the analysis of words containing the irregularity at the onset, we focused on the duration percentages of letters 1 and 2. For the words having the irregularity at the middle, we examined the duration percentages of letters 3 and 4. For the words with the irregularity at the end, we analysed duration percentages of letters 5 and 6 for six-letter words and 6 and 7 for seven-letter words.

Results

For each irregularity position, we conducted an Analysis of variance (ANOVA) with School level (1^{st}, 2^{nd} grade) as between-participants factor; the orthographic characteristics of the word (irregular, regular) and age of acquisition (early, late) were analysed as within-participants factors.

Onset

Figure 1 presents the mean stroke duration percentages for words acquired early and late at the Onset position. Analysis revealed no significant differences in duration percentage between grades 1 and 2. Grade level did not interact with any of the other factors. Mean duration percentages were higher for irregular words than for regular words ($F(1, 42) = 16.65$, $p < .001$). The effect of age of acquisition was also significant ($F(1, 42) = 16.08$, $p < .001$). The interaction between orthographic regularity and age of acquisition did not reach significance.

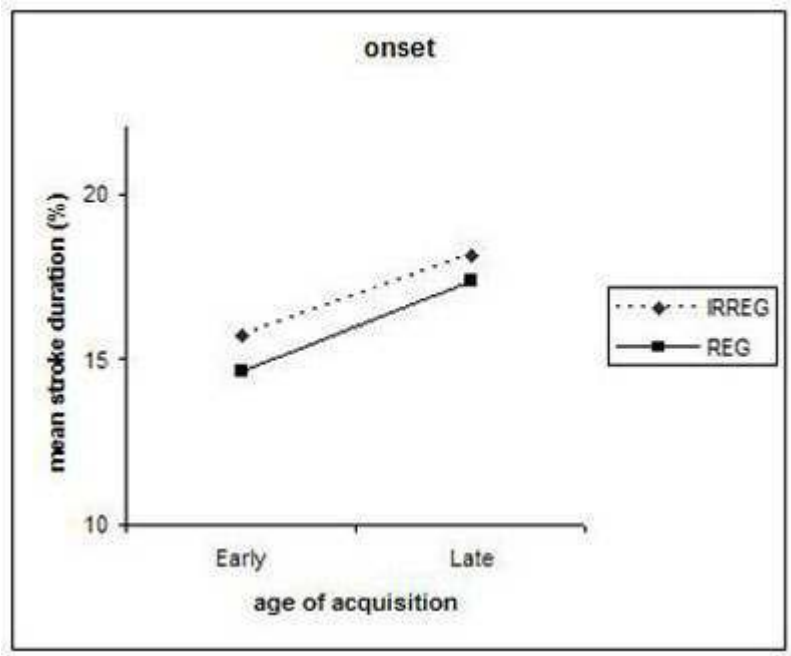

Figure 1. Mean stroke duration percentages for words acquired early and late in the Onset condition as a function of the orthographic characteristics of the word (irregular, regular).

Middle

Figure 2 presents mean stroke duration percentages for words acquired early and late at the Middle position. Again, there was no grade effect and this factor did not interact with any of the other variables. Means stroke duration percentages were higher for irregular words than regular ones ($F(1, 42) = 44.94$, $p < .001$) but the differences were significant only for the words acquired late ($F(1, 42) = 78.33$, $p < .001$). Age of acquisition was also

significant ($F(1, 42) = 77.24$, $p < .001$). The interaction between orthographic regularity and age of acquisition was significant ($F(1, 42) = 23.92$, $p < .001$).

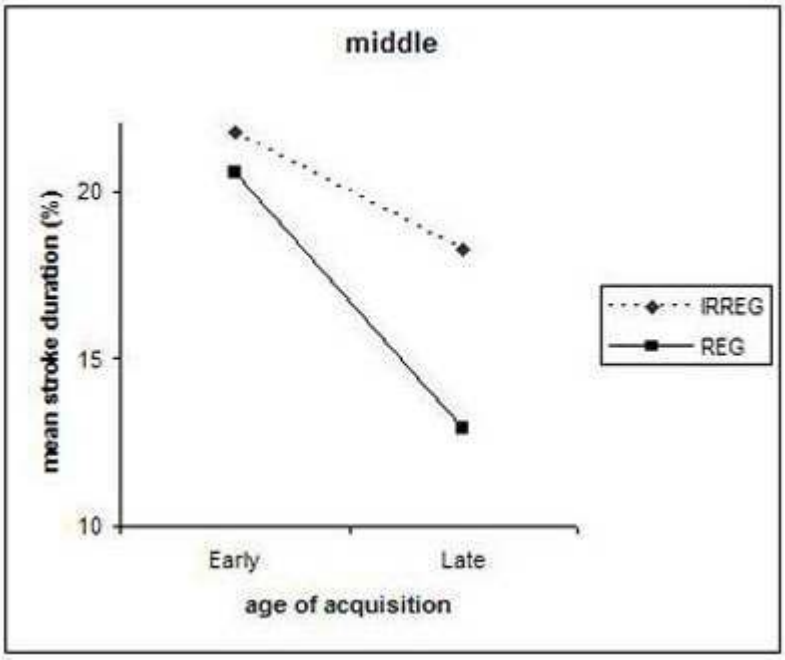

Figure 2. Mean stroke duration percentages for words acquired early and late in the Middle condition as a function of the orthographic characteristics of the word (irregular, regular).

End

Figure 3 presents mean stroke duration percentages for words acquired early and late at the End position. The ANOVA revealed no significant main effects of grade level. It did not interact with any of the other factors. Orthographic regularity did not yield significant effects. Age of acquisition was significant ($F(1, 42) = 10.12$, $p = .002$). The interaction between the two factors was significant ($F(1, 42) = 17.74$, $p < .001$). For words acquired early, duration percentages were higher for regular than irregular words ($F(1, 42) = 4.04$, $p = .05$). For words acquired late, duration percentages were higher for irregular than for regular words ($F(1, 42) = 18.21$, $p < .001$).

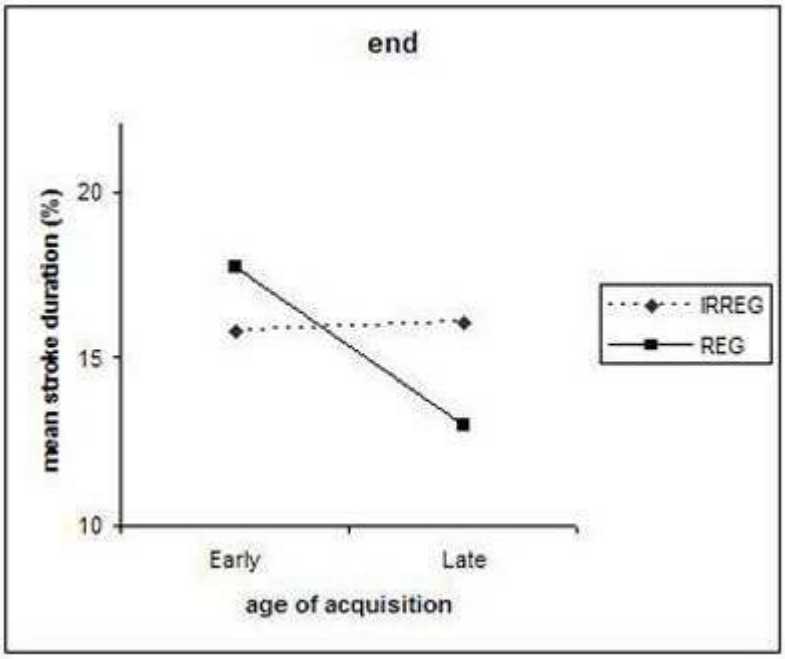

Figure 3. Mean stroke duration percentages for words acquired early and late in the End condition as a function of the orthographic characteristics of the word (irregular, regular).

Discussion

This study investigated whether orthographic irregularity constitutes a supplementary processing load in handwriting production during spelling acquisition. We used movement duration as an indicator of cognitive load. The orthographic irregularity was located at the beginning, middle or end of words acquired early or late. The results revealed that mean stroke duration percentages for irregular words were higher than for regular ones, both for first and second grade children. This pattern of results only reached significance for words acquired late.

The fact that the relative duration of critical letter strokes was higher for irregular than regular words indicates that orthographic irregularity constitutes a supplementary processing load with respect to the processing of regular words. However, the differences did not reach significance for words acquired early. This suggests that irregular words acquired early are already stored in the orthographic lexicon together with their orthographic characteristics and are accessed directly. There was no supplementary processing time because the children could recover the spelling from the lexicon, in the same fashion as for regular words. When the words are unfamiliar, their corresponding orthographic representations are likely to be unavailable (Share, 1995) or underspecified (Perfetti, 1992). The child therefore tends to apply phonological recoding rules. These rules work successfully when writing regular words (Share, 1995, 1999). The child reads the regular word on the screen, keeps its spelling in the graphemic buffer and programs the movement to write it down. When the child has to write an unfamiliar irregular word, this kind of operation fails. He/she has to memorize the spelling of the whole word and remember that there is a part of the word -the irregularity- that requires further attention. In other words, the spelling of the word is harder to keep in the buffer because there is no coherence between graphemes and phonemes at the position of the irregularity. Therefore, the strategy the child has to adopt to write the word without error is a) to process the identity and location of the letters that make the irregularity

separately; or b) to write the word by applying grapho-phonological conversion rules and realise that the rules do not apply at certain locations. Both kinds of operations constitute supplementary cognitive loads that are time consuming and result in an increase in processing time, as shown by Bloemsaat et al. (2003) in typing.

It should be noted that Kandel and Valdois (in press) showed that children program their handwriting movements according to the syllable structure of the word. In other words, they anticipate the letter sequences further ahead and program them before hand. The results presented in this paper for irregular words acquired late indicate that there is a more letter by letter programming. There are several reasons for these differences. The most important one is that Kandel and Valdois (in press) used very familiar regular bi-syllabic words. The children could therefore access their orthographic representation – i.e. their spelling- and then "unwrap" the word into the syllabic components that serve as input to the motor system. This is supported by the fact that in the present study there are no major differences between regular and irregular words when they are acquired early. Another relevant reason for these differences is that orthographic syllabification for irregular words is not as straightforward as for regular words. For example, where is the syllable boundary for the word *monsieur*? Phonologically, the syllabification is m/sj, but orthographically it is unclear to which syllable the *o* and *n* belong to because normally they represent the phoneme /õ/. So when the irregular word is unfamiliar, it is likely that the children apply a letter by letter processing mechanism that does not even consider syllable boundaries. Finally, note that in Kandel and Valdois (in press) first graders wrote some pseudo-words letter by letter, indicating that an analytic strategy can be applied when letter sequences are unfamiliar.

Furthermore, age of acquisition was significant at the three irregularity positions. For the onset position, the duration of critical letter strokes was lower for words acquired early than acquired late. This could be due to the fact that for the onset position the retrieval is done just before starting to write. Also, the retrieval and writing from an overlearned spelling dictionary is more efficient. For middle and end positions, the duration of the critical letter strokes was globally higher for words acquired early than acquired late. It seems that the retrieval by reconstruction through the application of phoneme-grapheme transcription rules is the more efficient way.

This study investigated the effect of orthographic regularity from a developmental perspective. We hypothesized that orthographic irregularity would affect first graders more than second graders. The results do not support this idea. There was no grade effect in any of the conditions. This could be due to the fact that the words acquired late were equally unfamiliar to first graders than to second graders. Another possibility is that second graders did have some kind of orthographic representation of the irregular words acquired late, but the spelling information was underspecified or insufficient (Perfetti, 1992). It should be pointed out that Bloemsaat et al. (2003) found an irregularity effect in adults. The irregularity effect when writing unfamiliar words could therefore be present in adulthood and not evolve during spelling acquisition. Further research is needed to assess this issue.

Finally, this experiment provides further evidence that linguistic variables such as orthographic regularity (Bloemsaat et al., 2003) and word familiarity (Søvik et al., 1994) affect written language performance by increasing movement time during word production. Movement time increases result from supplementary cognitive loads that arise from the parallel processing of the linguistic characteristics of the word and the

lower levels of handwriting production such as allograph selection, size control and muscular adjustments (Van Galen, 1991; Van Galen et al., 1986).

Appendix

Irregular and regular words for early and late acquired words. The orthographic irregularity appeared at the onset, middle and end of the word. In bold are indicated the orthographic irregularities of the irregular words.

	Irregular words		**Regular words**	
	Acquired early	Acquired late	Acquired early	Acquired late
Onset	quatre horloge	hurler mystère	diable bordure	border miracle
Middle	cahier bonheur	façade méthode	camion bonjour	farine microbe
End	soldat cadenas	désert paletot	sortir capital	détour panache

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ABSTRACTS

This study investigated how orthographic irregularity affects handwriting production during spelling acquisition. First and second graders wrote regular and irregular words on a digitiser. The orthographic irregularity was located at the beginning, middle or end of words acquired early and late. The results revealed that movement duration was always higher when writing irregular than regular words. However, the differences only reached significance for words acquired late. Therefore, regular and irregular words acquired early are accessed directly from the orthographic lexicon. A different mechanism operates when writing words acquired late. The child applies a phonological recoding operation that works successfully when writing regular words. When the child has to write an unfamiliar irregular word, he/she has to memorize the spelling of the whole word and remember the identity and location of the orthographic irregularity. This operation constitutes a supplementary cognitive load that results in an increase in processing time.

Ce travail étudie comment l'irrégularité orthographique des mots influence l'organisation graphomotrice de l'écriture. Des enfants de CP et CE1 ont écrit des mots réguliers et irréguliers sur une tablette digitalisante. L'irrégularité pouvait se trouver en début, milieu et fin de mots acquis tôt et tard. Les résultats montrent que les durées de production étaient plus importantes pour les mots irréguliers que pour les mots réguliers. Toutefois, les différences n'étaient significatives que pour les mots acquis tard. Les mots réguliers et irréguliers acquis tôt, seraient donc activés directement du lexique orthographique. Les mots acquis tard seraient traités par application de règles de recodage phonologique. L'écriture de mots réguliers serait satisfaisante. L'écriture de mots irréguliers nécessiterait la mémorisation de l'orthographe du mot entier ainsi que le rappel de l'identité et de la localisation de l'irrégularité orthographique. Cette opération constituerait une surcharge cognitive résultant en une augmentation de la durée de production.

INDEX

Keywords: children, French, orthographic regularity, handwriting

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